PVFS2 and Parallel I/O on BG/L

Rob Ross

Mathematics and Computer Science Division

Argonne National Laboratory

Special acknowledgements

- Rob Latham – did most of the work to get PVFS2 up and running
- Susan Coghlan – provided all the access we needed, made everything easy for us, and clicked the mouse at the right time (even from SLC!)
- Kazutomo Yoshii – figured out how to get things built for the IO nodes at Argonne
- LLNL group (Robin, Ira, others) – provided us with a great start for building IO node kernels
- IBM – provided source to key components and insight into system components that made this possible

Outline

- PVFS2 introduction and background
  - What it is, who it is, and why it's interesting for BG/L
- Base functionality for PVFS2 on BG/L
  - What is working, preliminary performance numbers
- Beyond the baseline
  - Pursuing higher I/O performance
  - Research in MPI-IO
- Wrap up

The PVFS2 Parallel File System

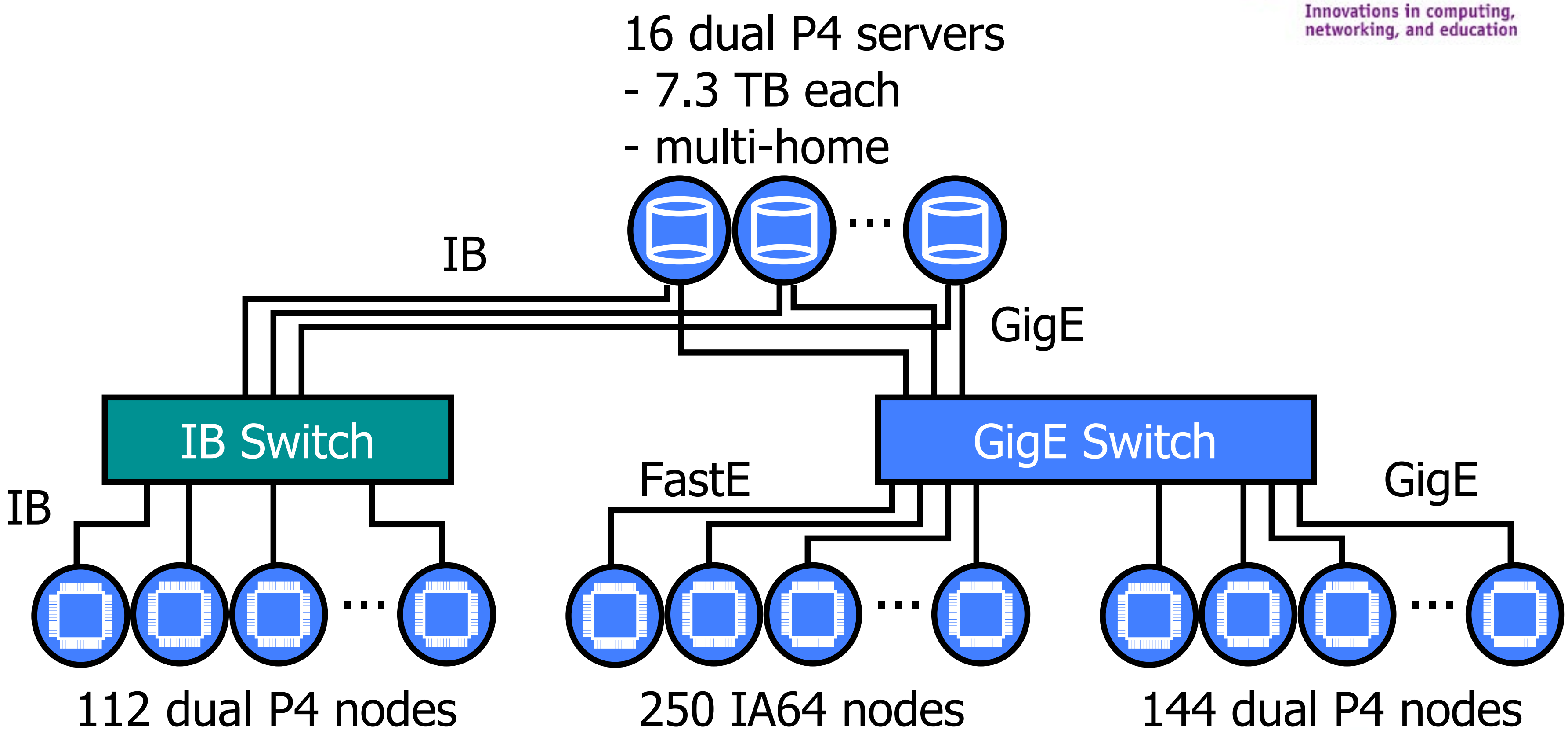
- <u>Parallel</u> file system
  - Distributed data and metadata
  - Tuned for performance and concurrency
- Production ready
  - In use at ANL, OSC, Univ. of Utah CHPC, others
- Open source and open development
  - LGPL license on all but kernel module, GPL on kernel module
  - Current CVS is anonymously accessible
  - Mailing lists where developers can track and initiate discussions
- Community research vehicle
  - Heterogeneous system support
  - Predominantly user-space code
  - Rapid porting via network and storage abstractions
  - Many labs and universities extend or modify PVFS2 to explore new ideas

Who is PVFS2?

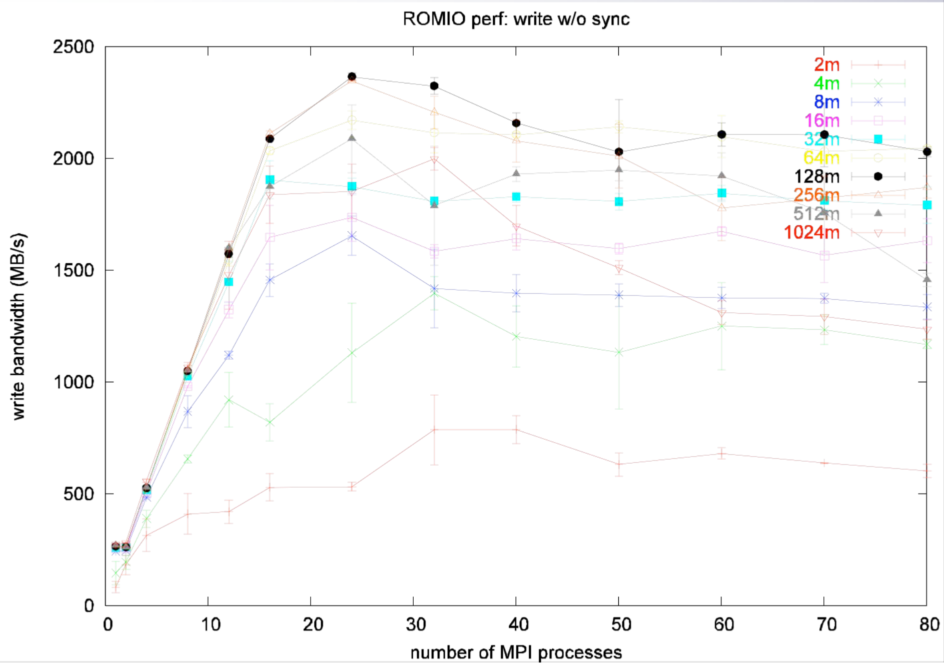
- PVFS2 is an open, collaborative effort
- Core development
  - Argonne National Laboratory
    - Ross, Latham, Gropp, Thakur
    - Supported by DOE Office of Science
  - Clemson University
    - Ligon, Settlemyer
  - Ohio Supercomputer Center
    - Wyckoff, Baer
- Collaborators
  - Northwestern University
    - Choudhary, Ching
  - Ohio State University
    - Panda, Yu
  - Penn State University
    - Sivasubramaniam, Kandemir, Vilayannur

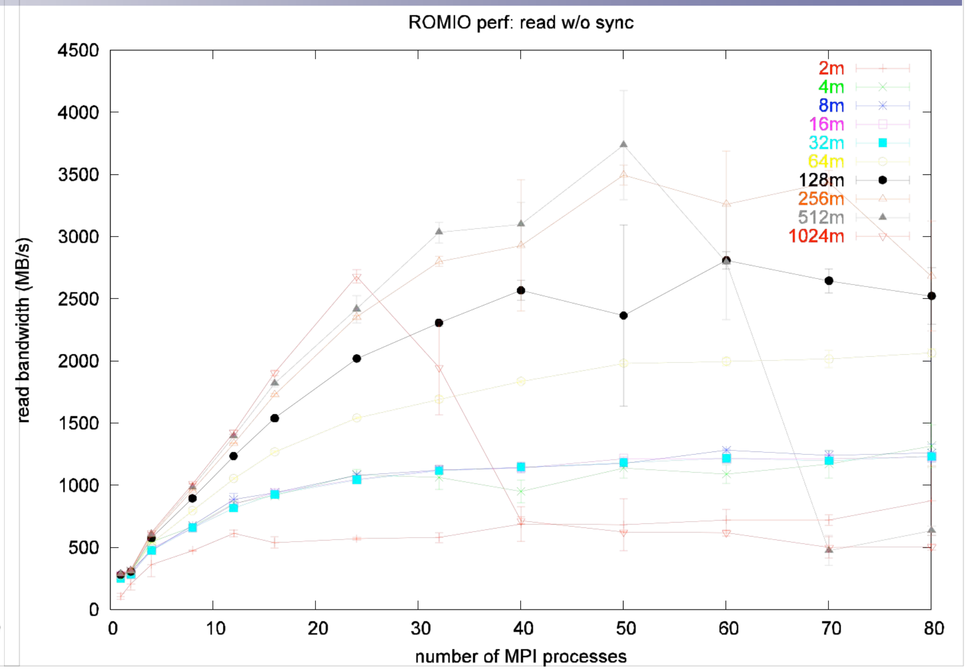
PVFS2 at OSC

- 506 total clients
- 116.8 TByte file system



OSC cluster performance

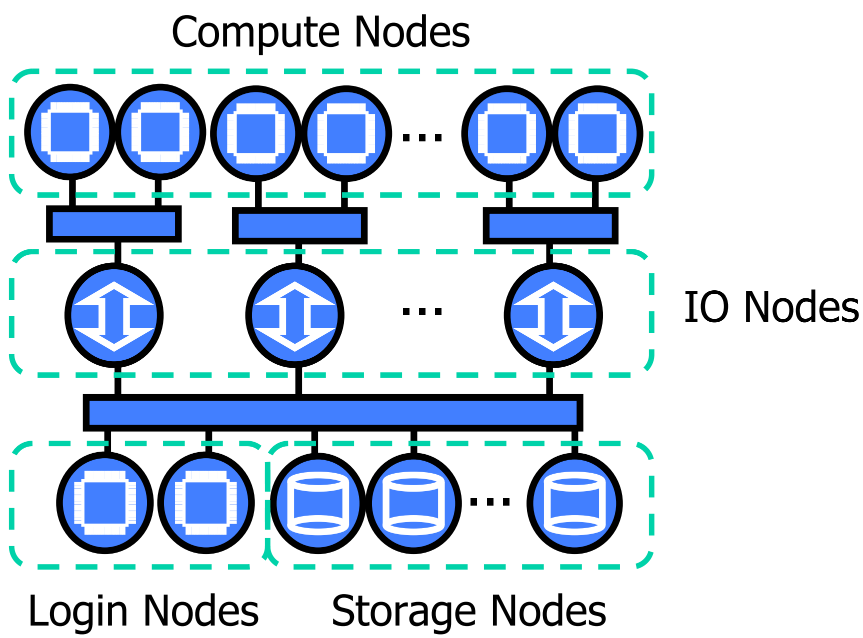




- Data sizes are per-client
- Achieving ~2.8GB/sec write, ~3.8GB/sec read
  - No network optimization (memory registration or pipelining)

View of I/O on BG/L

- Storage nodes
  - Local access to disks
  - GigE connections to login and IO nodes
- Login nodes
  - Interactive machines
  - Place where data staging will occur
- IO nodes
  - Aggregators for compute node I/O
    - 1:8 to 1:64 ratio of IO nodes to compute nodes
  - Tree connection to compute nodes
- Compute nodes
  - Source/sink of runtime I/O

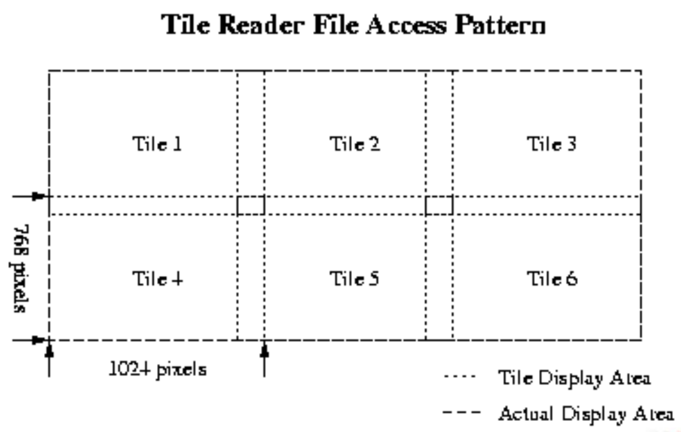


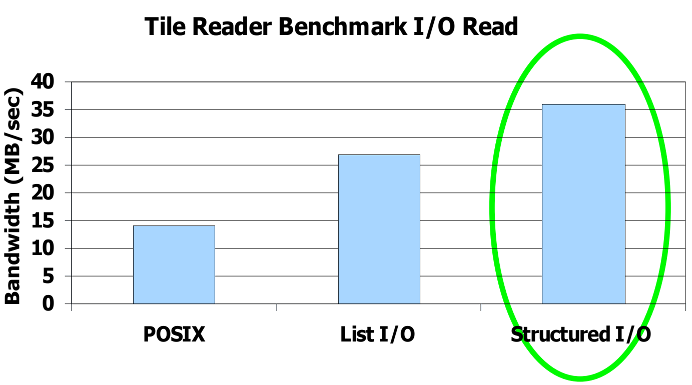
Why put PVFS2 on BG/L?

- It's fun ☺
- It provides another data point for I/O performance
- Most importantly, PVFS2 addresses three key scalability problems for parallel file systems:
  - I/O performance (especially for noncontiguous data)
  - Metadata performance (in particular open/close)
  - Failure tolerance
- Because of these advantages, we believe that PVFS2 has the best chance of extracting the highest possible I/O performance from BG/L

Scaling effective I/O rates

- POSIX I/O APIs aren't descriptive enough
  - Don't allow us to generally describe noncontiguous regions in both memory and file
- POSIX consistency semantics are too great a burden
  - Require too much additional communication and synchronization, not really required by many HPC applications
  - Will never reach peak I/O with POSIX at scale, only penalize the stubborn apps
  - Use more relaxed semantics at the FS layer as the default, build on top of that





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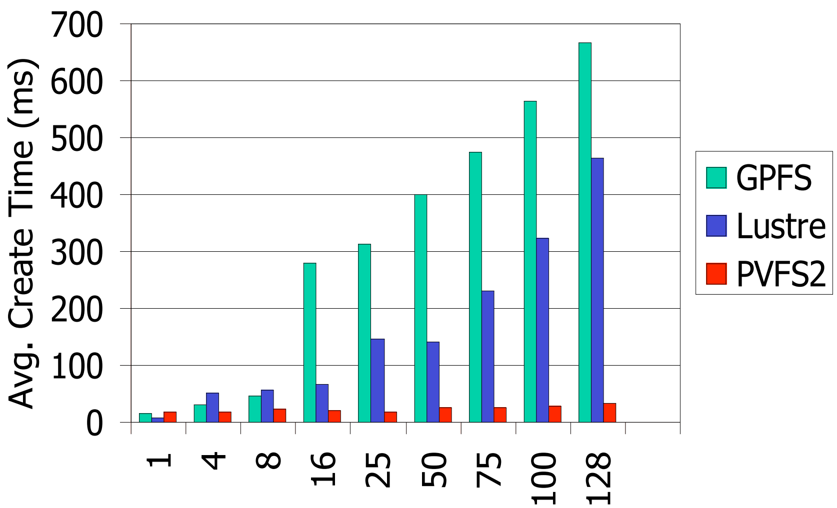
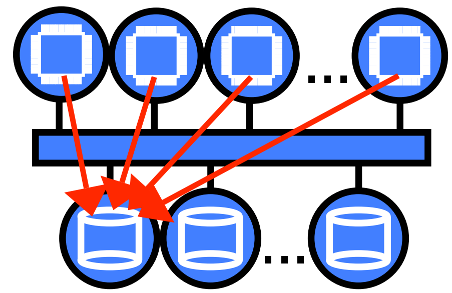
Scaling metadata operations

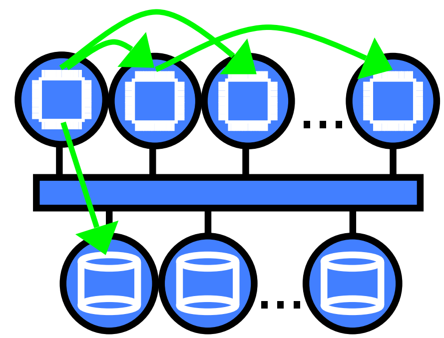
- POSIX API hinders scalability here too
  - POSIX open/close access model imposes constraints on how we implement MPI-IO operations like MPI_File_open
  - Similar issues with fsync and other operations

MPI File Create Performance (small is good)





POSIX file model forces all processes to open a file, causing system call storm.



Handle-based model uses a single FS lookup followed by broadcast of handle (implemented in ROMIO/PVFS2).

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Tolerating client failures

- Client failures are likely to be common with high node counts
  - 99.99% up indicates ~6 nodes down at any time on a 64K node system
  - 99.9% up indicates ~65 down at any time on same
- Unlike other options, PVFS2 uses a **stateless I/O model**
  - No locking system to add complications
  - No other shared data stored necessary for correct operation (no tracking of open files, etc.)
- Client failures can be ignored completely by servers and other clients
  - As opposed to locking systems, where locks and dirty blocks must be recovered!
- Server restarts are easily handled as well

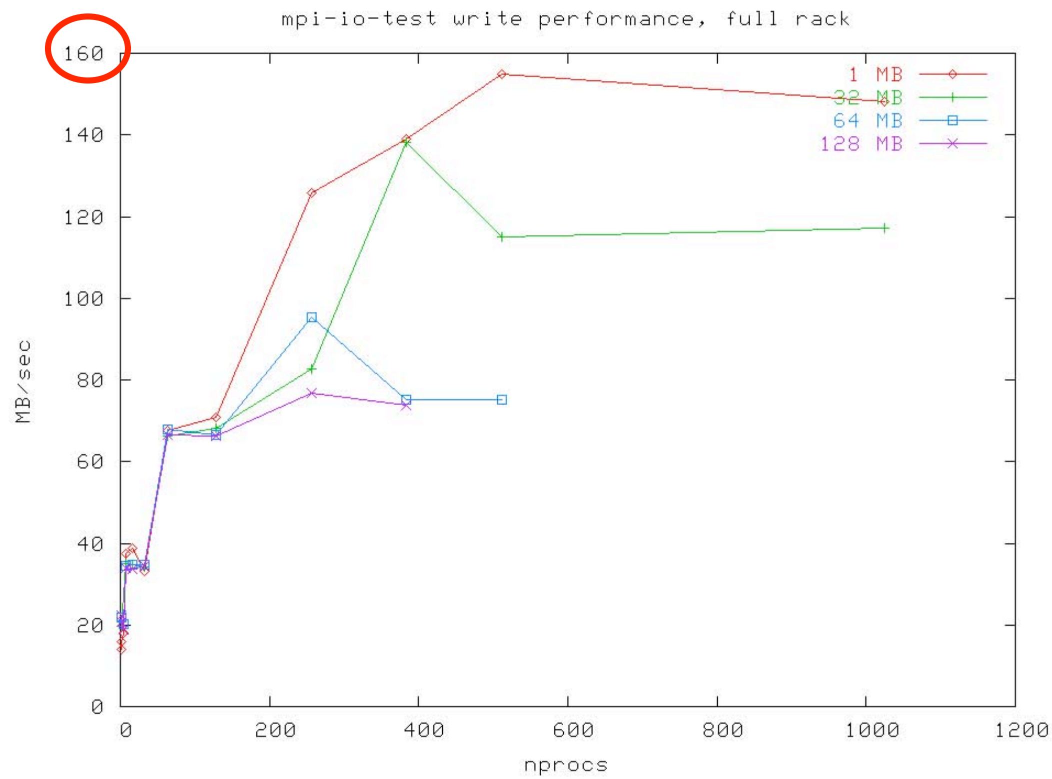
First steps in running PVFS2 on BG/L

- **Goal: Enable data staging and runtime I/O to a PVFS2 file system**
  - Run PVFS2 servers on storage nodes
    - dual Xeon nodes running SLES Linux and 2.6.5 kernel
  - Mount PVFS2 file system on login nodes
    - PowerPC 970 nodes running SLES Linux and 2.6.5 kernel
  - Mount PVFS2 file system on IO nodes
    - BG/L PowerPC nodes running 2.4.19 kernel (no longer MontaVista)
- **This only took two weeks to accomplish!**
  - Mostly learning/creating build environment
  - Minimal patching to PVFS2 (all in CVS)
  - 12 PVFS2 servers providing a single coherent file system

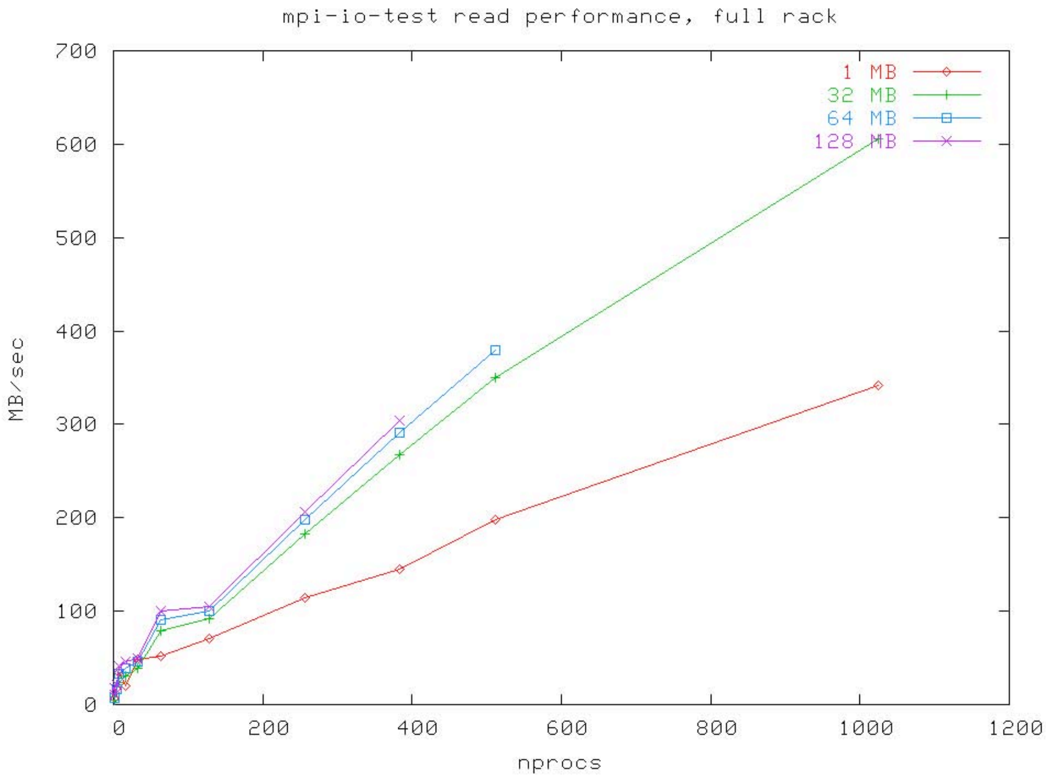
    (Assuming 900mbit/sec network to each, peak of ~1.3GB/sec raw BW)

Write performance (the bad news)

- Simple pattern:
  - Single file
  - Independent MPI-IO
  - One big access each
- We have more work to do here!
- ciod is breaking accesses into 95520 byte blocks
  - Understand why better now (Mike's talk)
  - Try tuning I/O message size
    - **What's the variable?**
  - Check TCP buffer sizes and turn on jumbo frames (Chris's talk)
  - Why does strace'ing the ciod kill our machine sometimes?
  - "Happy SuperComputing!" to you too ☺



Read performance (the good news)



- Peak of 600MB/sec (44% of raw BW, also no tuning)
  - This is **with** those tiny blocks…

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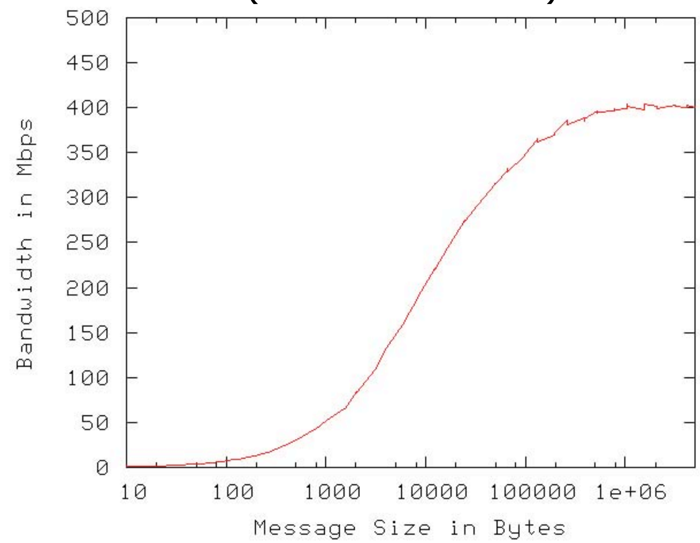
Beyond base functionality

- Our research indicates that the POSIX interface limits I/O scalability
  - Noncontiguous read and write performance
  - Open/close problems
- PVFS2 improvements cannot be seen through the VFS interface
  - BG/L has already broken POSIX, so on the right path…
  - We're still going through the VFS
  - The ciod is using POSIX calls
- **To obtain the highest possible performance we must circumvent (or change!) the VFS**
- Two options:
  - Direct compute node to storage server communication
  - **Retool communication between compute and IO nodes and mechanism IO node uses to access file system**

Direct PVFS2 access from compute nodes

- **Idea: Use PVFS2 client library directly on top of socket call forwarding to bypass IO node mount point**
- BGL PowerPC nodes
  - Special, proprietary kernel
  - Not all system calls are forwarded
- PVFS2 client code will (now) build for compute nodes, but
  - poll() and select() aren't implemented, so we can't run
- Interesting experiment, but not ideal solution…

TCP Bandwidth over Tree
(modified NetPIPE)



Changing the I/O language

- **Really what we'd like to do is change how compute processes talk to the file system**
  - Ideas prototyped in PVFS2 already
  - Allow for efficient noncontiguous I/O
  - Eliminate open() and close() scalability issues
  - More efficiently leverage the tree, IO node, and GigE
- This means changing how compute processes communicate with the IO node
  - Replace or augment existing ciod functionality
  - Map new language to PVFS2, GPFS, Lustre operations
    - **These changes can benefit any underlying file system**

I/O research in BG/L

- **Plan:** Experiment with new MPI-IO algorithms
  - Control of access mapping to IO nodes
  - Caching of data at IO nodes (to what extent possible)
  - New GPFS, Lustre, PVFS2 optimizations
- To do this, we must be able to rebuild ROMIO and link to IBM MPI
- **Next Tasks:**
  - ANL ensures that ROMIO builds cleanly against IBM MPI
  - IBM provides MPI without ROMIO

Wrap up

- In a couple of weeks we were able to get PVFS2 running on BG/L
  - Open source operating systems played a key role
  - Very positive experience!
- IBM developers have been very helpful
  - Will aid greatly in MPI-IO research and tuning for BG/L
- This is turning into an ideal platform for testing and deployment of next-generation I/O systems!
- High level libraries will follow as well
- We could use just a little more source… ☺

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Additional information on PVFS2

- PVFS2 web site: http://www.pvfs.org/pvfs2
  - Documentation, mailing list archives, and downloads
- PVFS2 mailing lists (see web site)
  - Separate users and developers lists
  - Please use these for general questions and discussion!
- Email
  - Rob Ross <rross@mcs.anl.gov>
  - Rob Latham <robl@mcs.anl.gov>

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